Expanded Polystyrene (EPS) Geofoam for Road Embankments and Other Lightweight Fills in Urban Environments

"Geoespuma" de Poliestireno Expandido (EPS) para Terraplenes en Carreteras y Otros Rellenos de Poco Peso en Ambientes Urbanos

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Abstract

The construction of fills for roads and other applications in an urban environment presents many technical and socioeconomic challenges. In recent years, the use of expanded polystyrene (EPS) blocks as a type of geofoam lightweight fill material has seen growing use worldwide in urban areas. This paper describes a recent project where EPS geofoam was used for a major road project in the U.S.A. Many of the benefits of using EPS as a lightweight fill in an urban environment were utilized on this project. Other recent uses of EPS geofoam are also noted.

Resumen

La construcción de terraplenes para carreteras y otras aplicaciones en ambientes urbanos presentan muchos retos técnicos y socioeconómicos. En años recientes, el uso de poliestireno expandido (EPS) en forma de bloques como material para relleno de poco peso ("geoespuma") se ha visto incrementado mundialmente en áreas urbanas. Este documento describe como recientemente se utilizó geoespuma EPS en un proyecto en una carretera principal en los Estados Unidos de América. Los muchos beneficios sobre la utilización de EPS como relleno de poco peso en ambientes urbanos fueron utilizados en este proyecto. También fueron incluidos en este documento otros usos recientes de geoespuma EPS.

1 INTRODUCTION

The construction of fills for roads and other purposes in an urban environment presents many technical and socioeconomic challenges to the civil engineer. The work must be designed and executed taking into account potential disruption to people, existing structures and infrastructure, and the environment. Aesthetic and archaeological issues as well as community involvement must also be considered. Nowadays, the benefit of what is referred to as *accelerated construction* is being appreciated more fully as there is a cost benefit, often difficult to quantify but nonetheless very real, to using newer technology that speeds construction to minimize the overall impacts. In addition to these socioeconomic issues, there are often one or more technical challenges involving soft ground, prior uncontrolled filling using nonearth materials, seismicity and karst topography that must be considered.

One of the newer innovations for constructing fills in an urban environment has been the use of lightweight materials. While such materials offer numerous benefits in a wide variety of conditions, they have proven to be particularly advantageous in dealing with the many challenges presented by construction in an urban setting. This is the reason for the urban focus of this paper.

2 EPS AS LIGHTWEIGHT FILL

In geotechnical structures such as fills, the mass of the fill material dominates both gravity and seismic design loads. Reduction of these loads is the primary reason for the significant worldwide growth in the use of lightweight (low-density) materials in earthworks. Examples of this global interest are recent development of a manual with design and specification guidelines for a wide variety of lightweight materials (*Matériaux* 1997) and inclusion of lightweight materials in a U.S. Federal Highway Administration (FHwA) short-course developed as part of FHwA Demonstration Project 116 on ground-improvement methods.

Expanded polystyrene (EPS), a type of plastic foam, has emerged as the material of choice for most earthworks that utilize a lightweight material. EPS is one type of *geofoam* which, together with *geocombs*, are now recognized as two families of *cellular geosynthetics*. While EPS has many distinct functional applications (Horvath 1995), the best known and most widely used to date is as a lightweight fill material.

The subject of this paper is the use of EPS geofoam as lightweight fill for a major, ongoing road project in Boston, Massachusetts, U.S.A. This particular project was chosen because it is a technically demanding one and illustrates most of the challenges faced when using EPS as a lightweight fill material in an urban setting. This project also utilized some of the latest thinking concerning design of EPS fills.

3 BENEFITS OF EPS LIGHTWEIGHT FILL

3.1 Introduction

The are many reasons why EPS has evolved as the lightweight fill material of choice, particularly in urban applications (Horvath 1995, Stark et al. 2002). Given the international scope of this conference, it is relevant to note that the benefits and advantages of EPS are not limited geographically. This is because EPS is a generic, commodity material that is manufactured locally in most countries. Thus EPS is not a technology that must be imported, and is available and used universally for diverse applications ranging from consumer products such as the ubiquitous white foam coffee cup to construction products such as geofoam. However, when used as lightweight fill it is typically molded as prismatic blocks that are of the order of 600x1200x2400 millimetres (2x4x8 feet), although longer blocks are increasingly common. In this form, EPS is referred to as *EPS-block geofoam*. Blocks can be used full size or factory cut to meet project-specific geometric requirements.

3.2 Design Issues

EPS has a density that is only 1% to 2% of that of soil, rock or portland-cement concrete (PCC). It is thus unique because it has a significantly lower density than all other lightweight fill materials such as foamed PCC, expanded shale, shredded tire chips, wood fiber and geocomb blocks (*Matériaux* 1997). Yet despite its uniquely low density, EPS has a remarkably high strength-to-density ratio and the standard material types available worldwide are capable of supporting long-term compressive stresses up to approximately 100 kPa (2000 lb/ft^2). This is comparable to many soils and, with proper design and construction, is more than adequate for supporting motor vehicles, trains, aircraft and even lightly loaded structures.

Because of its uniquely low density, the use of EPS as lightweight fill generally does not require using additional ground improvement techniques such as preloading or soil mixing when soft-ground conditions exist at a project sire. This also reduces costs and accelerates construction.

EPS is a true solid, not a particulate material like soil, expanded shale, or waste materials such as shredded tires. As a result, fills consisting of EPS blocks are inherently self-stable with vertical side slopes. This has numerous benefits that include reduced material and construction costs as well as minimizing right-of-way land requirements which can be particularly important in urban settings.

3.3 Construction Issues

EPS blocks typically arrive at a project site in their necessary size and shape, and thus ready to be placed. Construction can be done in most any temperature or weather conditions. Only unskilled manual labor is required to place EPS blocks. This minimizes costs as no specialized construction trades or expensive heavy machinery with skilled operators is required. There is also no noise, dust or odor that is directly attributable to using EPS which is also particularly important in urban environments.

3.4 Durability

With proper care to prevent damage during construction (an important consideration with all types of geosynthetics) as well as prevent contact with certain liquids such as gasoline, EPS is extraordinarily durable once placed in the ground (Horvath 1999). There is no known maximum life to EPS in the ground as it is inherently stable chemically in normal soil and groundwater conditions. Thus EPS does not have any of the in-ground durability issues that can be a concern with other types of polymeric (plastic) geosynthetics. The mechanical (stress-strain) properties of EPS are not affected by in-ground burial, including water absorption.

3.5 Environmental Issues

EPS is environmentally friendly and safe during manufacturing, construction and in the ground. Unlike many other plastic foams, no gases that are harmful to the Earth's upper-atmosphere ozone layer are used to make EPS and no potentially harmful gases are given off once properly seasoned EPS is placed in the ground. Unlike some waste materials that are used as lightweight fill, there is no potential for chemical changes or reactions in the ground that may result in spontaneous combustion or the creation of toxic substances.

4 EXAMPLE APPLICATION

4.1 Overview

The project discussed in this paper is the Central Artery/Tunnel (CA/T) Project. This massive public-works project, which is referred to as the "Big Dig", has as its focus the total reconstruction of Interstate highway I-93 as it passes through the heart of the City of Boston and the extension of Interstate I-90 from its terminus at I-93 just south of downtown Boston to Logan International Airport in east Boston.

The technical challenges facing the design and construction of the CA/T Project are many and varied. Overall, the Project has complex and tight schedules that must be followed in a densely developed urban environment that includes:

- Elevated roads, roads and railways at grade, and road and rail tunnels.
- Maintaining traffic on the existing I-90 and I-93 until the new roads and connecting ramps are completed.
- Soft ground conditions throughout most of the Project area, including filled-in portions of Boston Harbor.
- Project-wide seismic design requirements.

The end result of these factors has been the extensive use of numerous innovative, state-of-art structural and geotechnical engineering technologies on the CA/T Project.

4.2 Contract C09C2

To manage and facilitate both design and construction of such a large project, work has been divided up into 118 separate construction contracts. The subject of this paper is Contract C09C2 (I-93/I-90 Interchange, Ramps and Surface Restoration at Albany Street). This contract encompasses viaducts, bridges, transition structures, U-shaped "boat" sections, and tunnel sections on I-93 and connecting to I-90 as well as roadways at grade for the South Bay interchange.

The particular components of Contract C09C2 that are relevant to this paper are eight transition structures and ramps on I-93 and also connecting to existing I-90 and other surface roadways and boat sections south of downtown Boston and South Station. The preliminary design for these structures called for a combination of precast-PCC girder bridges with curtain walls on both sides; elevated slabs; and soil-filled boat sections, each supported on deep foundations. A cost and schedule initiative to accelerate construction on Contract C09C2 proposed replacement of each these eight transition structures and ramps with roadway embankments consisting primarily of EPS-block geofoam as a lightweight fill material. In all cases, the EPS embankments rest on existing grade. The use of EPS-block geofoam as a lightweight fill material resolved the primary technical challenge of constructing an elevated finished roadway in an area underlain by extremely soft soils.

4.3 Design Requirements

The first step in any design is to clearly define the project-specific design criteria. The principal issues that were considered in the redesign of all eight transition structures and ramps on Contract C09C2 are:

- No net stress increase is allowed on the existing soil subgrade.
- The ramps have a variety of vertical profiles and horizontal curve alignments. The average ramp width is typically of the order of 8 metres (25 feet). Heights vary with some ramps up to 8 metres (25 feet) high.

- Because of right-of-way constraints, the width of the overall ramp structure must be more or less constant over its entire length. This means that if a fill is used it must have vertical sides. Because of the CA/T Project architectural requirements, these vertical sides must have a certain aesthetic appearance to achieve uniformity with adjacent structures. This limits the choice of facing materials.
- In some cases, temporary ramps occupy the same general alignment as a permanent ramp. Therefore the presence, construction sequencing and ultimate removal of the temporary ramp must be considered in the analysis, design details and construction of the permanent ramp.
- All CA/T Project structures must be designed for seismic loading in conformance with the seismic design requirements of the Standard Specification of Highway Bridges published by the American Association of State Highway and Transportation Officials (AASHTO). In this case, Seismic Performance Category (SPC) "B" with a bedrock horizontal seismic acceleration of 0.17*g* applies. As the Contract C09C2 site is generally underlain by soft fine-grain soil with a depth to bedrock in excess of 30 metres (100 ft), amplification of the bedrock motion at the existing ground surface must be considered. These soil conditions correspond to AASHTO-defined Soil Type III which corresponds to a seismic-amplification factor of 1.5.
- The Contract C09C2 area is close to the Fort Point Channel of Boston Harbor which is connected to the Atlantic Ocean. Thus the potential for flooding to a defined elevation established for the CA/T Project must also be considered.

4.4 Reference Documents Used in Design

In the preliminary design phase of the EPS embankments for Contract C09C2, the CA/T Project design team was provided access to the 2000 interim (Phase I) report of National Cooperative Highway Research Program (NCHRP) Project 24-11 for Fiscal Year 1998 titled "Guidelines for Geofoam Applications in Embankment Projects" (Stark et al. 2000). The final (Phase II) NCHRP Project 24-11 report was issued in 2002 (Stark et al. 2002) and incorporated the key components of the Phase I report. This final report will eventually be released to the public.

Based on material presented in the NCHRP Project 24-11/FY1998 Phase I report as well as requirements outlined in the AASHTO Standard Specification of Highway Bridges, the CA/T Project design team developed separate documents with design criteria and a detailed numerical example that were specific to the CA/T Project. Both of these documents considered technical issues that were unique to the analysis and design of the relatively slender fills to be implemented on Contract C09C2.

The CA/T Project design team also developed contract specifications that were tailored to the requirements of Contract C09C2. The CA/T Project specification is based on the material presented in the NCHRP Project 24-11/FY1998 Phase I report. The key elements of this specification can also be found in Horvath (2001). The Contract C09C2 specification is believed to be the first use of what will hopefully be adopted as the first AASHTO standard for EPS geofoam as lightweight fill in road construction.

4.5 Seismic Loading

Most of the current state-of-knowledge regarding the behavior of EPS fills under seismic loading is the result of research conducted since the late 1980s under the auspices of the EPS Development Organization (EDO) in Japan. This research consists of a broad spectrum of reduced- and full-scale shake-table tests, numerical analyses, and the observation of actual fills that were subjected to major earthquakes.

Based on initial, early EDO research, two different models and modes of behavior were considered possible for an EPS fill used beneath a road:

- Rigid-body sliding of an "active" wedge of EPS blocks behind some type of earth retaining structure. This is applicable for those areas where the EPS blocks are placed behind, say, a bridge abutment.
- Horizontal sway of an assemblage of EPS blocks as an equivalent elastic cantilever beam fixed at its base. The behavior is modeled as a classical single-degree-of-freedom (SDOF) system. This is applicable for behavior of EPS fills in a plane perpendicular to the alignment of a roadway.

In both models, which are discussed in detail in (Horvath 1995), the EPS fill is assumed to be essentially massless compared to the mass contributed by the approximately one metre (3 feet) of total pavement section (this includes both bound and unbound materials) that is typically placed on top of the EPS.

Of particular interest and relevance to the Contract C09C2 design was the most-recent series of EDO shake-table tests that was performed in the late 1990s. These were the first such tests conducted at full-scale. Published summaries of these tests (Nishi et al. 1998, Hotta et al. 1998) indicated an unrecognized third mode of EPS-fill behavior that is now referred to as *seismic rocking*. A detailed discussion of this behavioral mode and its consequences for design can be found in Riad et al. (2003). Given the very limited distribution of this reference, its contents were republished in Horvath (2003).

The CA/T Project design team recognized the potential for this newly identified behavioral mode of seismic rocking in the transverse direction for the Contract C09C2 EPS ramps and transition structures. Analyses indicated that this mode was actually the controlling factor in the design of many of the Contract C09C2 EPS structures under the combination of dead and earthquake loading prescribed in conformance with AASHTO group loading. The validity of this design outcome was demonstrated by the above-described EDO shake-table tests. As discussed by Nishi et al. (1998) and Hotta et al. (1998), the lowest level of EPS blocks in the EDO shake-table test fills, which had not been designed for seismic rocking, were clearly crushed at the end of the tests.

It is believed that this is the first time, at least in U.S. practice, that seismic rocking has been considered for an EPS fill. The fact that it was found to govern the design in this case suggests that it is a behavior mode that should be considered for all EPS embankments where seismic loading is appropriate.

4.6 Side Covering

The use of EPS fills with vertical sides, also called *geofoam walls* (Horvath 1995), has been increasing rapidly in recent years worldwide. Such fills are very beneficial, particularly in crowded urban areas, as the width of right-of-way required for the fill is minimized. This translates into savings in material costs and construction costs and time in addition to environmental and public-relations benefits.

There are, however, technical consequences to the use of vertical-side fills that must also be considered so that the total costs can be properly evaluated. These include:

- Although an assemblage of EPS blocks with vertical sides is completely self-stable, the exposed EPS surfaces must be covered to prevent long-term surficial degradation due to UV exposure and incidental physical damage as well as to provide an appropriate architectural finish.
- Current design practice suggests that the use of a reinforced-PCC slab, sometimes referred to as *load distribution slab* (LDS), on top of the EPS blocks is mandatory for a vertical-side EPS fill. The slab is often used as a connection point for the vertical side-covering system of the fill. It also provides anchorage for various elements of "road hardware" such as safety barriers, signage, lighting, drainage structures, and utilities.
- Actual project bid experience in the U.S.A. indicates that both the side covering and LDS represent relatively significant cost components of the overall construction cost of an EPS-block geofoam fill (Stark et al. 2002).

The use of a LDS could not be eliminated on Contract C09C2. Therefore the cost-saving focus was on the side-covering system. For an EPS fill, the facing system is primarily an architectural element performing an aesthetic function. It is also important to note that any relatively massive facing alternative such as precast PCC panels is likely to require its own foundation. Under the poor soil conditions that typically exist with EPS fills, such facing systems may require the use of deep foundations. Using deep foundations in this context is counterproductive to the basic idea of implementing a lightweight fill material for a highway embankment to save cost and schedule time.

Among the massive facing alternatives, full-height precast PCC panels have proven to be particularly popular in U.S. practice in recent years and were the design alternative considered initially for use on the EPS structures on Contract C09C2. Such panels would have been similar to precast PCC curtain walls utilized on adjoining transition structures and ramps in the South Bay area. However, in those areas a relatively expensive deep-foundation system was required to support the heavy precast walls. In addition, analyses indicated that under seismic loading PCC facing panels for the Contract C09C2 EPS fills would have transmitted a relatively significant horizontal inertia force (approximately 25% of their mass) to the assemblage of EPS blocks.

Following completion of the original design, the CA/T Project design team actively investigated wall-facing alternatives. Ultimately, an alternative was chosen that, as best as can be determined, has never been used previously for an EPS fill on a road project although it was suggested at an international symposium on EPS geofoam as far back as 1994 (Horvath 1995). This alternative involves the use of EIFS (*Exterior Insulation Finishing System*), a well-proven technology that has been used worldwide for decades with buildings. EIFS consists of a mesh-reinforced, two-part cementitious covering applied over a plastic-foam substrate, most often a relatively thin (of the order of 50 millimetres (2 inches)) panel of EPS. The final appearance of the EIFS coating can vary widely for architectural purposes but is most often finished to create a stucco-like appearance. As a result, EIFS is often referred to as "synthetic stucco". The overall attraction of an EIFS system is that, if properly applied and maintained, it is very durable in the long-term in a wide variety of climates. The specific attraction for the Contract C09C2 EPS fills was that the EIFS panels are relatively light, i.e. they could be attached to and supported by the exposed EPS blocks. The end result would be a durable, architecturally attractive side panel system that was very cost effective and help reduce overall construction schedule through the elimination of deep foundation supporting the facing.

5 OTHER URBAN APPLICATIONS

Although this paper has focused on a road application, there are numerous other uses of EPS-block geofoam as a lightweight fill in urban environments. To date it has been used in other transportation earthworks involving railways and airfields. It has also been used for landscaping and even to directly support the shallow foundations of lightly loaded buildings and small bridges. In general, it has been and can be used in any application where the long-term applied stresses do not exceed approximately 100 kPa (2000 lb/ft^2).

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